

REGULAR ORIGINAL FILING

Application Based on

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**ORGANIC ELEMENT FOR ELECTROLUMINESCENT DEVICES**

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## **ORGANIC ELEMENT FOR ELECTROLUMINESCENT DEVICES**

### **FIELD OF INVENTION**

This invention relates to organic light emitting diode (OLED)  
5 electroluminescent (EL) device comprising a light-emitting layer containing a  
rubrene dopant compound containing aryl or heterocyclic groups attached to the  
end rings of the naphthacene nucleus.

### **BACKGROUND OF THE INVENTION**

10 While organic electroluminescent (EL) devices have been known  
for over two decades, their performance limitations have represented a barrier to  
many desirable applications. In simplest form, an organic EL device is comprised  
of an anode for hole injection, a cathode for electron injection, and an organic  
medium sandwiched between these electrodes to support charge recombination  
15 that yields emission of light. These devices are also commonly referred to as  
organic light-emitting diodes, or OLEDs. Representative of earlier organic EL  
devices are Gurnee et al. U.S. Pat. No. 3,172,862, issued Mar. 9, 1965; Gurnee  
U.S. Pat. No. 3,173,050, issued Mar. 9, 1965; Dresner, "Double Injection  
Electroluminescence in Anthracene", RCA Review, Vol. 30, pp. 322-334, 1969;  
20 and Dresner U.S. Pat. No. 3,710,167, issued Jan. 9, 1973. The organic layers in  
these devices, usually composed of a polycyclic aromatic hydrocarbon, were very  
thick (much greater than 1  $\mu\text{m}$ ). Consequently, operating voltages were very high,  
often >100V.

More recent organic EL devices include an organic EL element  
25 consisting of extremely thin layers (e.g. <1.0  $\mu\text{m}$  ) between the anode and the  
cathode. Herein, the organic EL element encompasses the layers between the  
anode and cathode electrodes. Reducing the thickness lowered the resistance of  
the organic layer and has enabled devices that operate at much lower voltage. In a  
basic two-layer EL device structure, described first in US 4,356,429, one organic  
30 layer of the EL element adjacent to the anode is specifically chosen to transport  
holes, therefore, it is referred to as the hole-transporting layer, and the other  
organic layer is specifically chosen to transport electrons, referred to as the

electron-transporting layer. The interface between the two layers provides an efficient site for the recombination of the injected hole/electron pair and the resultant electroluminescence.

5           There have also been proposed three-layer organic EL devices that contain an organic light-emitting layer (LEL) between the hole- transporting layer and electron-transporting layer, such as that disclosed by Tang et al [*J. Applied Physics*, Vol. 65, Pages 3610-3616, 1989]. The light-emitting layer commonly consists of a host material doped with a guest material - dopant , which results in an efficiency improvement and allows color tuning.

10           Since these early inventions, further improvements in device materials have resulted in improved performance in attributes such as color, stability, luminance efficiency and manufacturability, e.g., as disclosed in US 5,061,569, US 5,409,783, US 5,554,450, US 5,593,788, US 5,683,823, US 5, 908,581, US 5,928,802, US 6,020,078, and US 6,208,077, amongst others.

15           Notwithstanding these developments, there are continuing needs for organic EL device components, such as dopants, that will provide high luminance efficiencies combined with high color purity and long lifetimes.

          A useful class of dopants is that derived from 5,6,11,12-tetraphenylnaphthacene, also referred to as rubrene. The solution spectra of these  
20           materials are typically characterized by wavelength of maximum emission, also referred to as emission  $\lambda_{\text{max}}$ , in a range of 550-560nm and are useful in organic EL devices in combination with dopants in other layers to produce white light. However, the range of light emitted by rubrene derived dopants limits the purity of the white light produced in OLEDs. In order to achieve OLEDs that can  
25           produce higher purity white light, one needs to have the ability to increase the range of maximum emission, or emission  $\lambda_{\text{max}}$  of the rubrene derived dopants so that they can be matched spectrally with the emission of dopants in the other light producing layers. Useful dopants are those that emit light in solution in the range of 560-650nm, and particularly in the 565-625nm range, have good efficiency and  
30           sublime readily.

          Yellow light is generally defined as having a wavelength range in the visible region of the electromagnetic spectrum of 570-590nm, orange light

590-630nm and red light 630-700nm, as defined by Dr. R.W.G.Hunt in *The Reproduction of Colour in Photography, Printing & Television, 4<sup>th</sup> Edition 1987, Fountain Press, page 4*. When light has a spectral profile that overlaps these ranges, to whatever degree, it is loosely referred to as yellow-orange or orange-red.

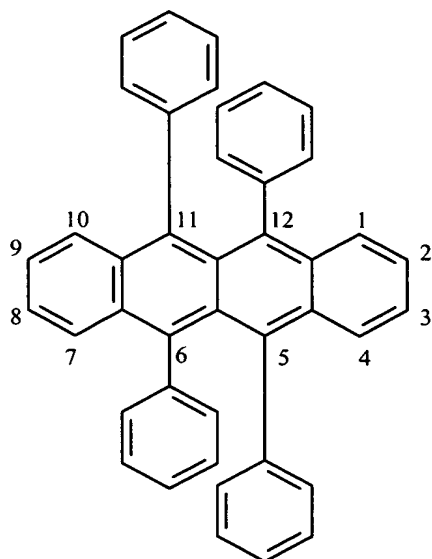
US 6,399,223; EP 1,148,109A2; JP20001156290A; and JP 04335087 discloses the use of rubrene derivatives containing either 2 phenyl groups on one end ring of the rubrene structure or 4 phenyl groups on both end rings. There is no teaching of a single phenyl group on each end ring of the rubrene structure.

However, these rubrene derivatives do not produce the desired emission  $\lambda_{\max}$ . Thus devices containing these rubrene derivatives fail to provide white OLED devices with high color purity.

The problem to be solved is to provide a dopant compound for a light-emitting layer of an OLED device that provides white light purity, and high luminance efficiency.

### SUMMARY OF THE INVENTION

An OLED device comprising a light-emitting layer (LEL) containing a host and a dopant located between a cathode and an anode wherein the emitter is an orange-red light emitting rubrene derivative represented by formula (I):



Formula (I)

wherein:

- a) there are identical aromatic groups at the 2- and 8-positions;
- 5        b) the phenyl rings in the 5- and 11-positions contain only para-substituents identical to the aromatic groups in paragraph a); and
- c) the phenyl rings in the 6- and 12-positions are substituted or not.

The invention also provides a display including such a device and a  
10    method of imaging using such a device.

Such a device exhibits long wavelength electroluminescence  
desirable in the production of high purity white light.

#### BRIEF DESCRIPTION OF THE DRAWINGS

15        FIG. 1 shows a cross-section of a typical OLED device in which  
this invention may be used.

#### DETAILED DESCRIPTION OF THE INVENTION

The invention is generally as described above.

20        An OLED device of the invention is a multilayer  
electroluminescent device comprising a cathode, an anode, charge-injecting layers

(if necessary), charge-transporting layers, and a light-emitting layer (LEL) comprising a host and at least one dopant, a rubrene derivative. The term rubrene refers to 5,6,11,12-tetraphenylnaphthacene as defined by the *Grant & Hackh's Chemical Dictionary*, Fifth Edition, McGraw-Hill Book Company, page 512 and  
5 *Dictionary of Organic Compounds*, Fifth Edition, Chapman and Hall, Volume 5, page 5297. The term naphthacene is the chemical name used to describe four linearly fused benzene rings as defined by the *Grant & Hackh's Chemical Dictionary*, Fifth Edition, McGraw-Hill Book Company, page 383.

Suitably, the light-emitting layer of the device comprises a host and  
10 dopant where the dopant is present in an amount of up to 10%-wt of the host, more typically from 0.1-5.0%-wt of the host. The dopant is suitably a 2,5,6,8,11,12-hexaphenylnaphthacene, and usefully a 5,6,11,12-tetraphenylnaphthacene with an aromatic heterocyclic group at the 2 and 8-positions of the naphthacene. Good results are obtained when the phenyl or  
15 heterocyclic groups are substituted, particularly where the substituent groups are fluorine, fluorine containing groups, alkyl, aryl, alkoxy or aryloxy groups.

Useful dopants of the invention are those that emit light in ethyl acetate solution such that  $560\text{nm} < \lambda_{\text{max}} \leq 650\text{nm}$  and preferable  $565\text{nm} < \lambda_{\text{max}} \leq 625\text{nm}$  and have good efficiency. Combined with other light emitting dopants, the  
20 dopants of the invention can be used to produce white light. The other light emitting dopants are usefully dopants that emit blue or blue-green light.

Blue light is generally defined as having a wavelength range in the visible region of the electromagnetic spectrum of 450-480nm, blue-green 480-510nm, green 510-550, green-yellow 550-570nm, yellow 570-590nm, orange 590-630nm  
25 and red 630-700nm, as defined by Dr. R.W.G.Hunt in *The Reproduction of Colour in Photography, Printing & Television*, 4<sup>th</sup> Edition 1987, Fountain Press, page 4. Suitable combinations of these components produce white light.

Another embodiment of the invention comprises additional layers  
30 incorporating dopants the light from which in combination with the orange-red

light of the rubrene derivative combine to give white light. Such additional dopants can be chosen so that they emit blue or blue-green light.

5 In another embodiment of the invention when additional layers are present so that the emitted light is white, a filter capable of controlling the spectral components of the white light such as red, green and blue, can be placed over-lying the device to give a device useful for color display. Suitably, each light-emitting layer of the device comprises a host and dopant where the dopant is present in an amount of up to 10%-wt of the host, more typically from 0.1-5.0%-wt of the host

10

The benefit imparted by the dopant does not appear to be host specific. Desirable hosts include those based on amine compounds but not limited to such compounds. One particularly example of a host is *N,N'*-di-1-naphthalenyl-*N,N'*-diphenyl-4, 4'-diaminobiphenyl (NPB)

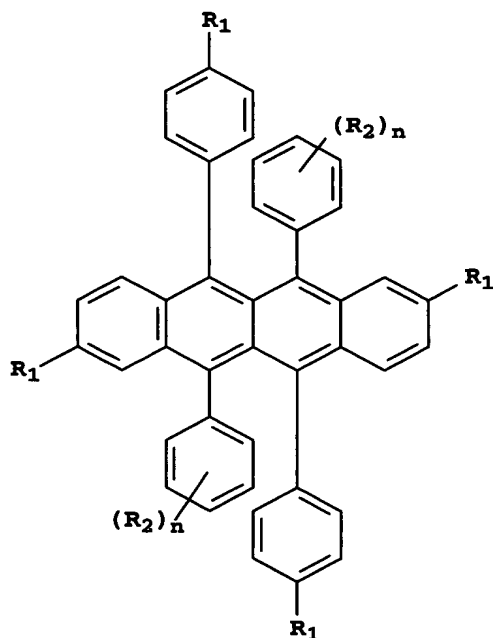
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Embodiments of the dopants useful in the invention provide an emitted light having an orange-red hue. In combination with the dopants of the invention, additional dopants that emit blue or blue-green light in additional layers, results in the formation of white light. Substituents on the dopants of the invention are selected to provide embodiments that exhibit a reduced loss of initial

20

luminance compared to the device containing no rubrene compound.

Formula (II) suitably represents compounds useful in the invention:



Formula (II)

wherein

$R_1$  is an aromatic carbocyclic or heterocyclic group;

$R_2$  is a substituent group;

5  $n$  is 0-5;

provided that all  $R_1$  are the same; and

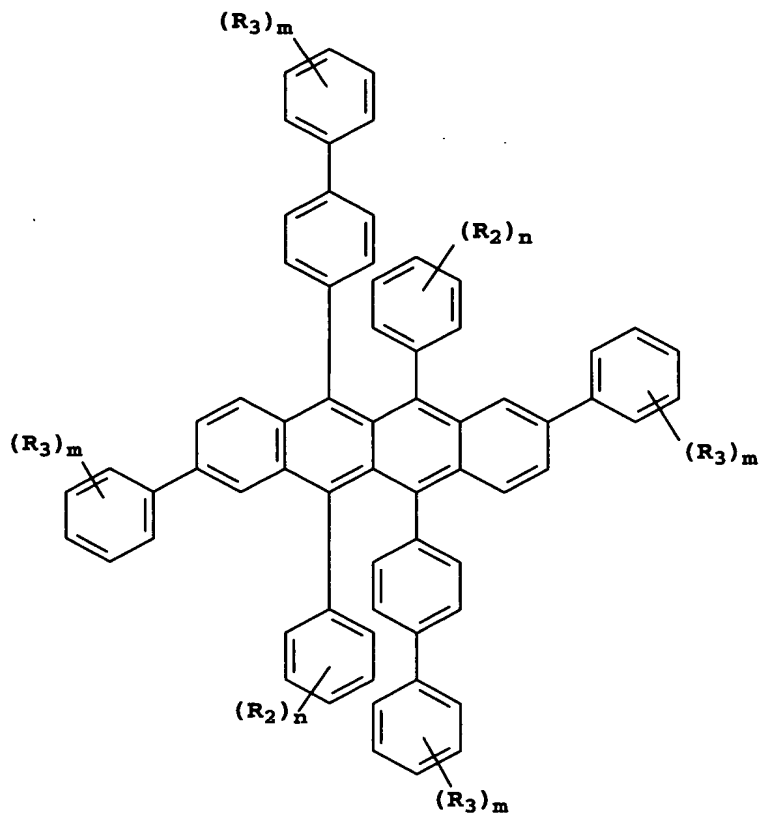
provided further, that the  $R_2$ , their location and  $n$  value on one ring are the same as those on the second ring.

Particularly useful rubrene derivatives are those represented by formula  
 10 (II) wherein  $R_2$  is a substituent group located in the meta or para-position of the phenyl ring.

A particularly useful embodiment of the invention is represented  
 by formula (III):

15





Formula (III)

wherein

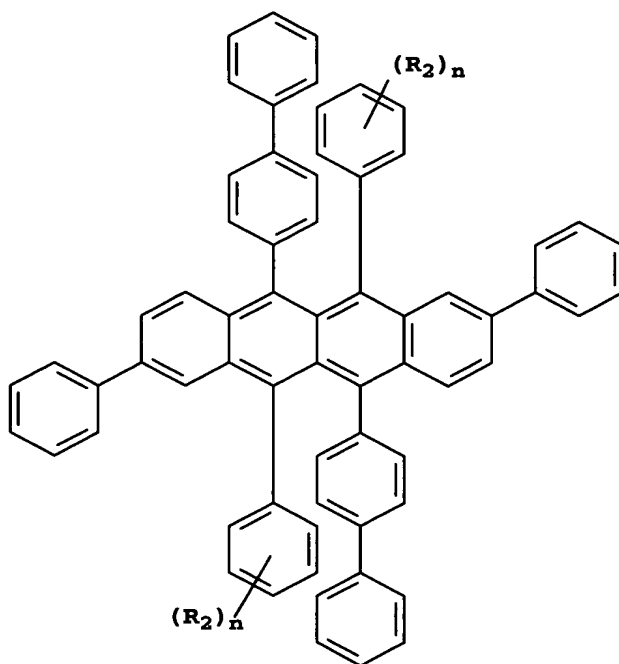
$R_2$  and  $R_3$  are independently selected substituent groups;

$n$  and  $m$  are independently 0-5;

5 provided that the  $R_2$ , their location and  $n$  value on one ring are the same as those on the second ring; and

provided further, that the  $R_3$ , their location and  $m$  value on one ring are the same as those on all rings containing  $R_3$ .

10 A further useful embodiment of the invention where  $m$  in formula (III) is 0, is represented by formula (IV):



Formula (IV)

In formulae (II)-(IV) useful in the device, all  $R_1$  groups are the same and are conveniently aromatic carbocyclic or heterocyclic groups.

- 5 Particularly useful  $R_1$  groups are phenyl groups. The phenyl or heterocyclic groups can be substituted with halide, particularly fluorine or fluorine containing groups such as trifluoromethyl, pentafluoroethyl or fluorinated-phenyl groups, alkyl, aryl, alkoxy, and aryloxy groups. In the device, the  $R_2$  groups on one phenyl group are the same as those on the diagonally opposite phenyl group, in
- 10 terms of location and number. The term "diagonally opposite phenyl group" refers to the location of the phenyl groups on the naphthalene nucleus. The phenyl groups in the 5- and 11-positions or the 6- and 12-positions are diagonally opposite each other. The  $R_2$  groups are selected from the group consisting of halide, alkyl, aryl, alkoxy, and aryloxy groups. In one useful embodiment, the  $R_2$
- 15 groups are selected from the group consisting of fluorine, alkyl, and aryl groups. A desirable embodiment is where  $R_2$  is fluorine or a fluorine-containing group such as trifluoromethyl, pentafluoroethyl or fluorinated-phenyl.  $R_2$  and  $R_3$  can also be hydrogen. The  $R_2$  groups may be located in the ortho, meta and para positions on the phenyl ring, but preferably in the meta and para positions. When

R<sub>2</sub> is fluorine it can be located in either of the ortho, meta or para positions, or it may be located in any combination of these positions or in all of these positions.

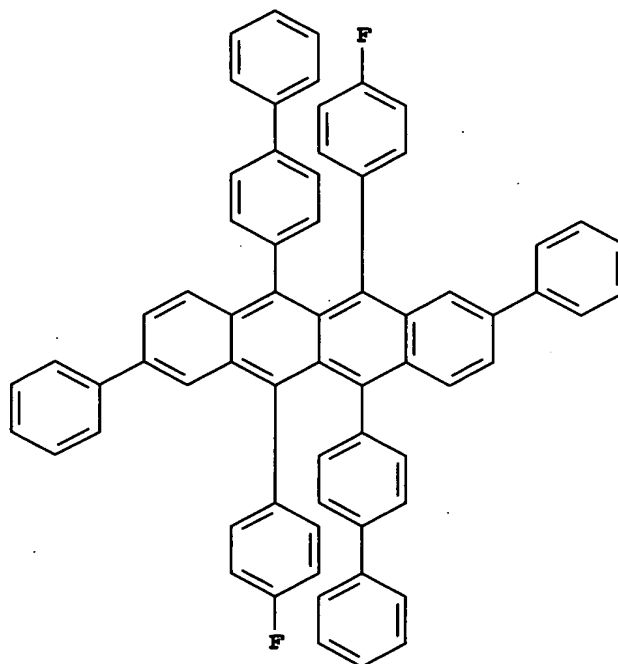
The emission wavelength of these compounds may be adjusted to some extent by appropriate changes to R<sub>1</sub>, R<sub>2</sub> and R<sub>3</sub> groups to meet a color aim, 5 namely orange-red.

The rubrene compound is usually doped into a host compound, which represents the light-emitting layer between the hole-transporting and electron-transporting layers. The host is chosen such that there is efficient energy transfer from the host to the rubrene compound. The rubrene compound emits from the excited state to afford a bright, highly efficient, stable EL device.

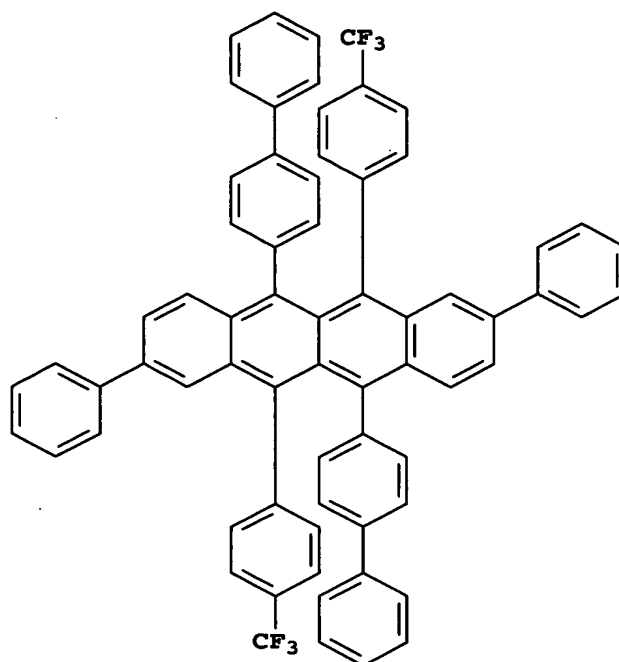
The EL device of the invention is useful in any device where light emission is desired such as a lamp or a component in a static or motion imaging device, such as a television, cell phone, DVD player, or computer monitor.

15 Illustrative examples of rubrene compounds useful in the present invention are the following:

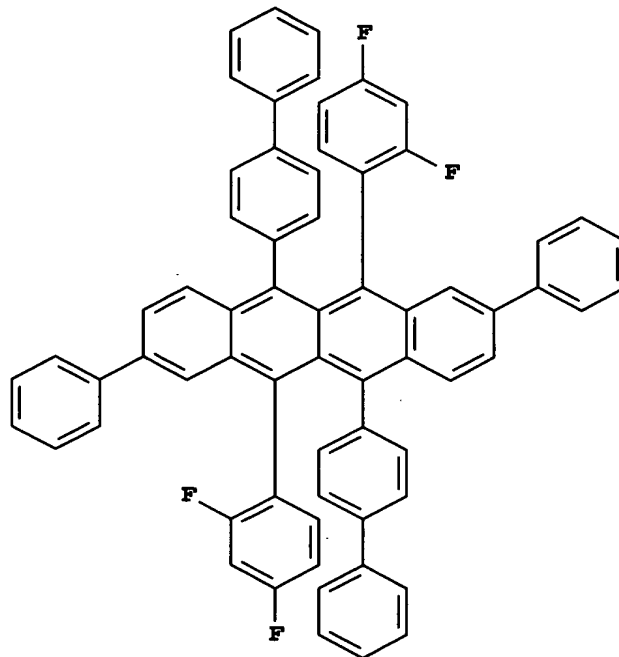
## Inv-1



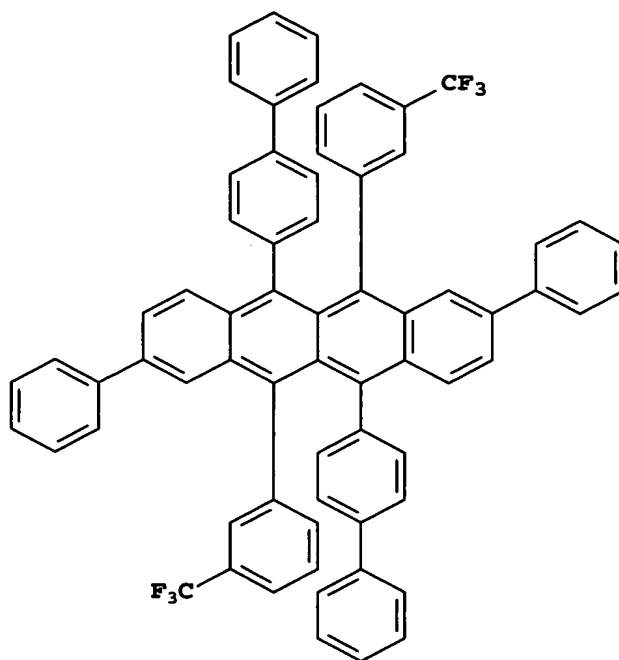
**Inv-2**



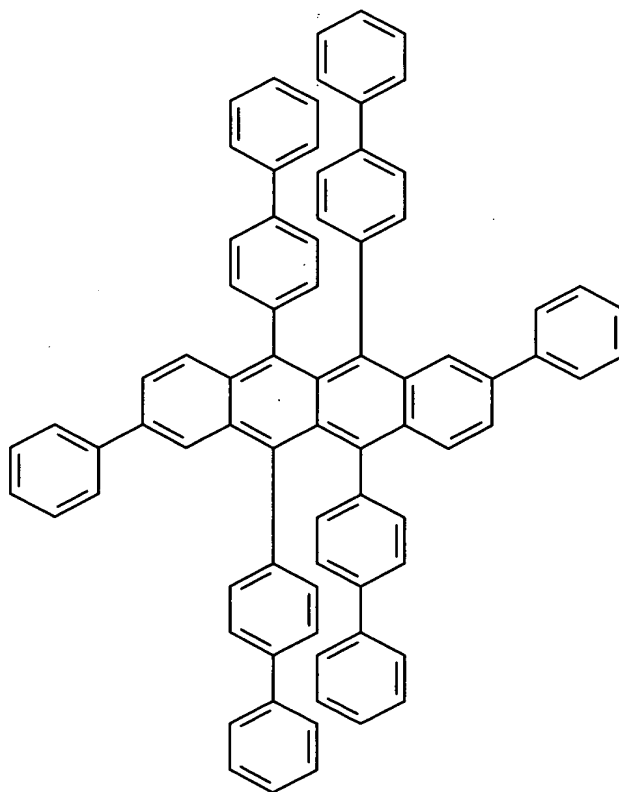
**Inv-3**



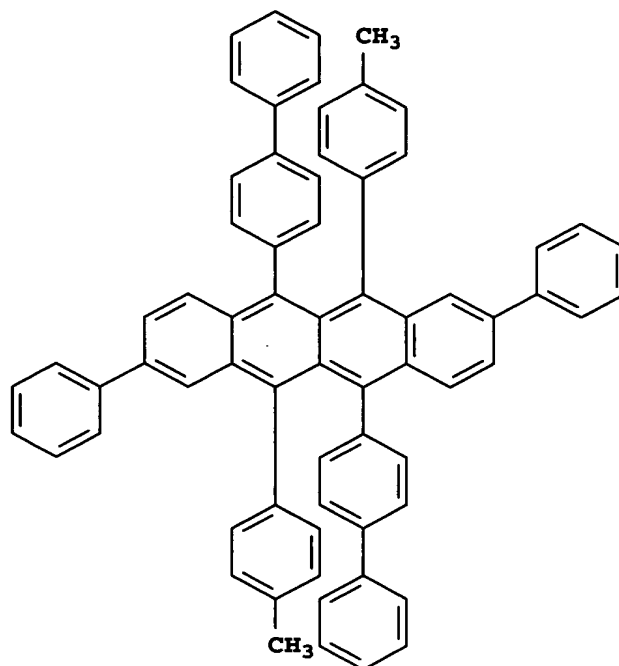
**Inv-4**



**Inv-5**

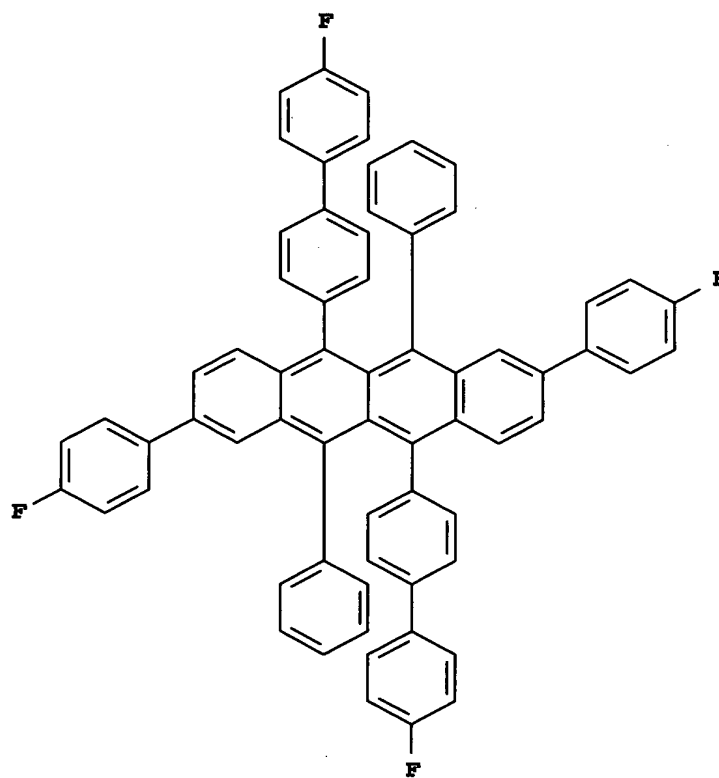


**Inv-6**

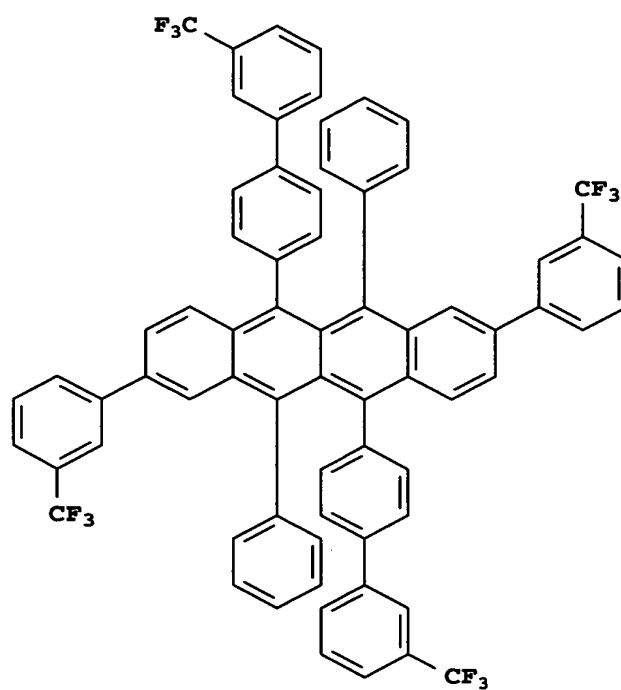


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**Inv-7**

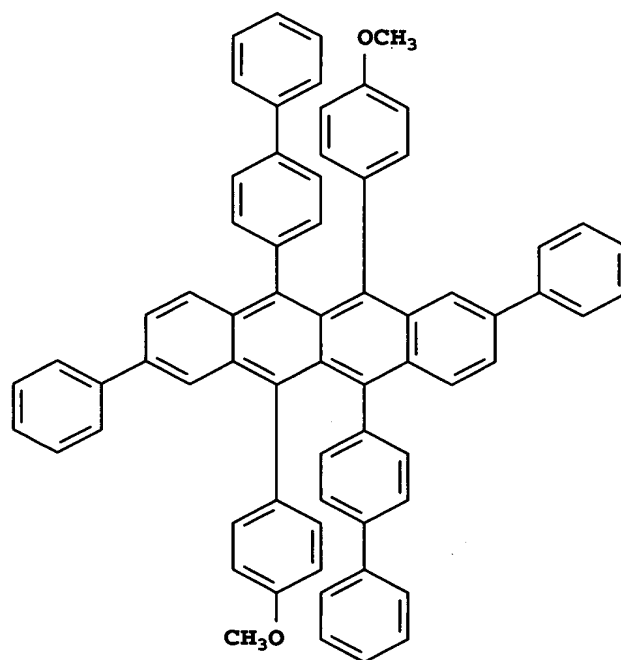


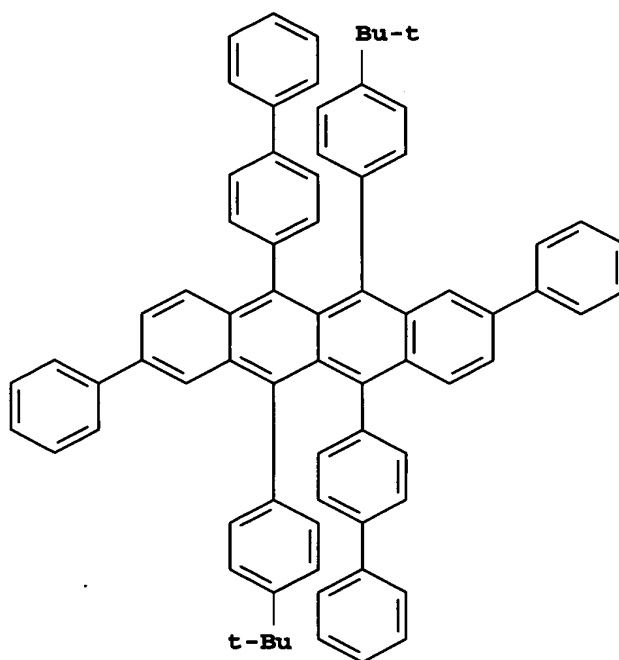
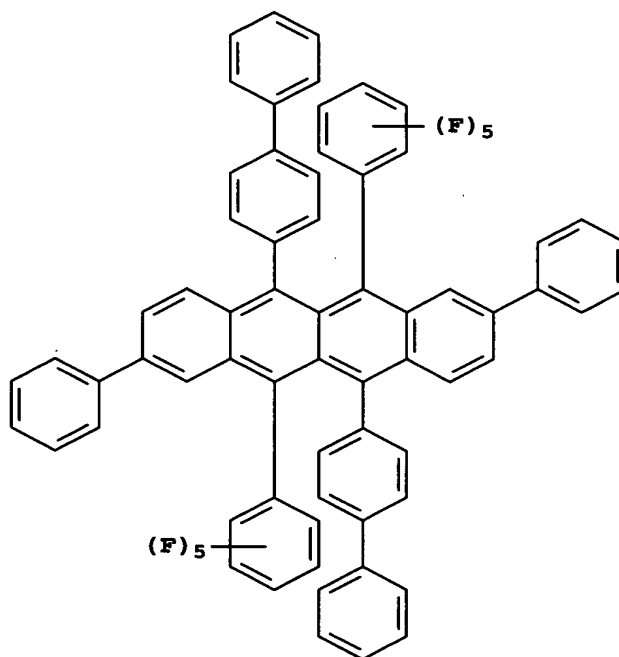
**Inv-8**



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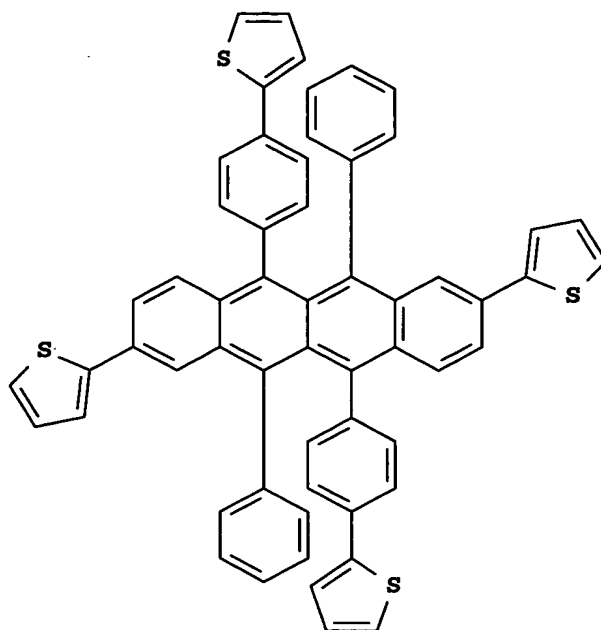
**Inv-9**



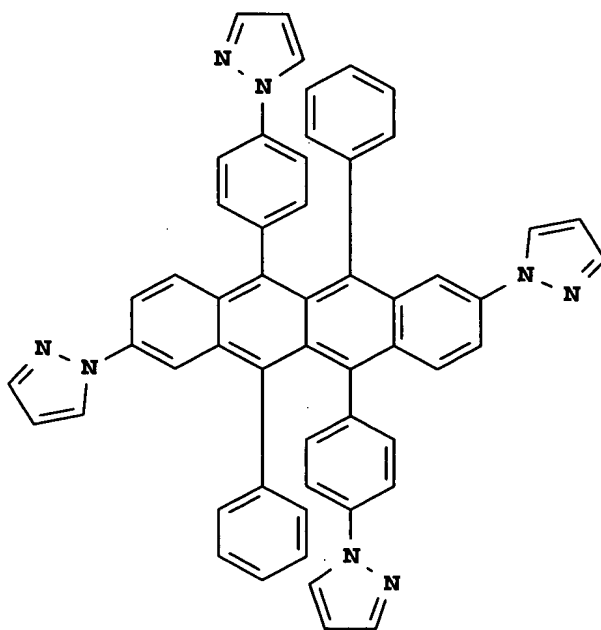
**Inv-10****Inv-11**



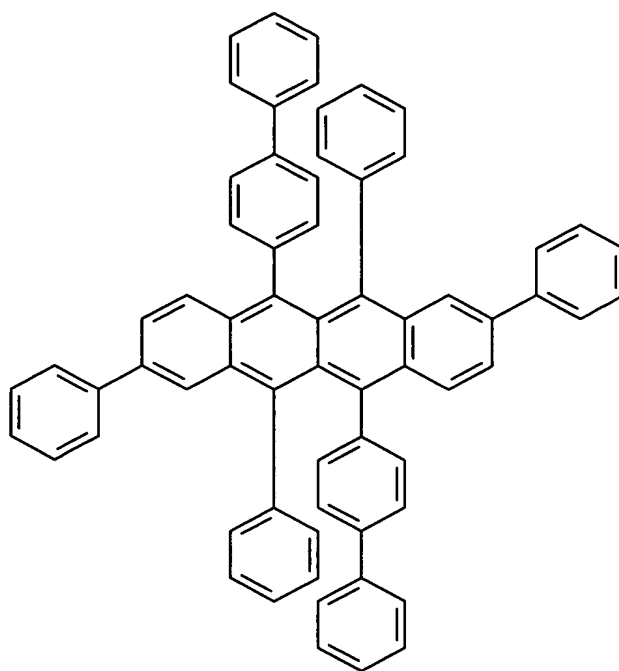
**Inv-12**



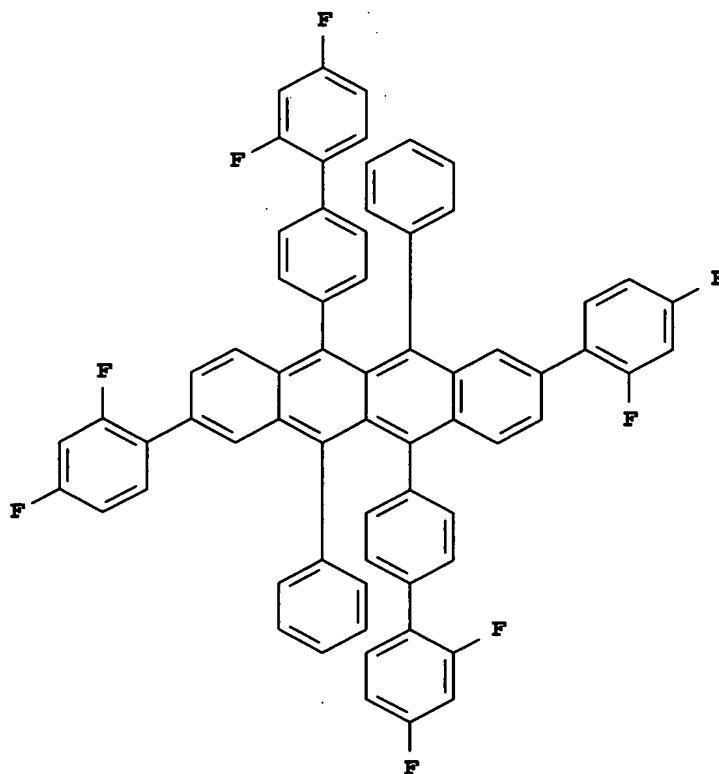
**Inv-13**



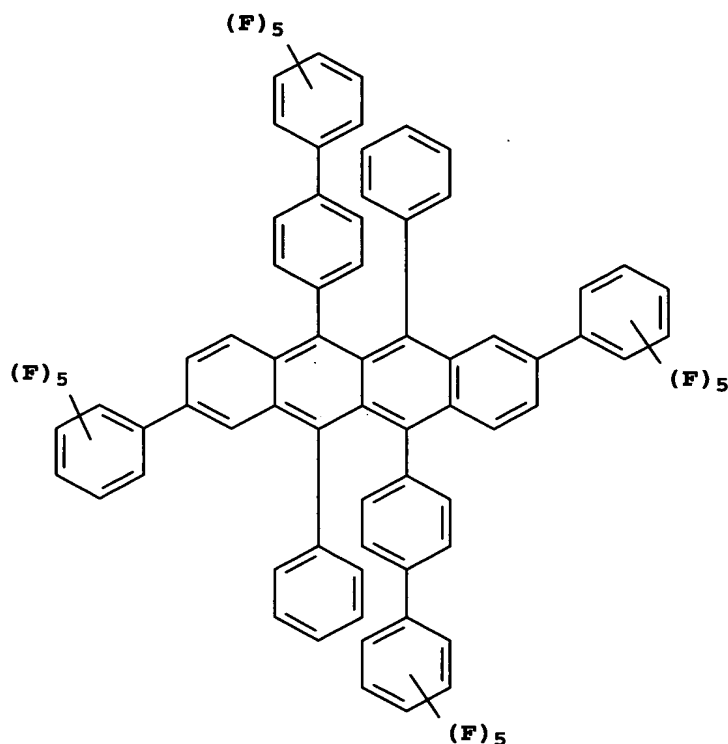
**Inv-14**



**Inv-15**



**Inv-16**



Embodiments of the invention provide not only emission  $\lambda_{\max}$  shifted to longer wavelength but also high luminance efficiency and a more desirable orange-red hue as evidenced by the location and shape of the absorption curve of the emitted light.

Unless otherwise specifically stated, use of the term "substituted" or "substituent" means any group or atom other than hydrogen. Additionally, when the term "group" is used, it means that when a substituent group contains a substitutable hydrogen, it is also intended to encompass not only the substituent's unsubstituted form, but also its form further substituted with any substituent group or groups as herein mentioned, so long as the substituent does not destroy properties necessary for device utility. Suitably, a substituent group may be halogen or may be bonded to the remainder of the molecule by an atom of carbon, silicon, oxygen, nitrogen, phosphorous, sulfur, selenium, or boron. The substituent may be, for example, halogen, such as chloro, bromo or fluoro; nitro;

hydroxyl; cyano; carboxyl; or groups which may be further substituted, such as alkyl, including straight or branched chain or cyclic alkyl, such as methyl, trifluoromethyl, ethyl, *t*-butyl, 3-(2,4-di-*t*-pentylphenoxy) propyl, and tetradecyl; alkenyl, such as ethylene, 2-butene; alkoxy, such as methoxy, ethoxy, propoxy, butoxy, 2-methoxyethoxy, *sec*-butoxy, hexyloxy, 2-ethylhexyloxy, tetradecyloxy, 2-(2,4-di-*t*-pentylphenoxy)ethoxy, and 2-dodecyloxyethoxy; aryl such as phenyl, 4-*t*-butylphenyl, 2,4,6-trimethylphenyl, naphthyl; aryloxy, such as phenoxy, 2-methylphenoxy, alpha- or beta-naphthyloxy, and 4-tolyloxy; carbonamido, such as acetamido, benzamido, butyramido, tetradecanamido, alpha-(2,4-di-*t*-pentylphenoxy)acetamido, alpha-(2,4-di-*t*-pentylphenoxy)butyramido, alpha-(3-pentadecylphenoxy)-hexanamido, alpha-(4-hydroxy-3-*t*-butylphenoxy)-tetradecanamido, 2-oxo-pyrrolidin-1-yl, 2-oxo-5-tetradecylpyrrolin-1-yl, *N*-methyltetradecanamido, *N*-succinimido, *N*-phthalimido, 2,5-dioxo-1-oxazolidinyl, 3-dodecyl-2,5-dioxo-1-imidazolyl, and *N*-acetyl-*N*-dodecylamino, ethoxycarbonylamino, phenoxycarbonylamino, benzyloxycarbonylamino, hexadecyloxycarbonylamino, 2,4-di-*t*-butylphenoxycarbonylamino, phenylcarbonylamino, 2,5-(di-*t*-pentylphenyl)carbonylamino, *p*-dodecylphenylcarbonylamino, *p*-tolylcarbonylamino, *N*-methylureido, *N,N*-dimethylureido, *N*-methyl-*N*-dodecylureido, *N*-hexadecylureido, *N,N*-dioctadecylureido, *N,N*-dioctyl-*N*'-ethylureido, *N*-phenylureido, *N,N*-diphenylureido, *N*-phenyl-*N*-*p*-tolylureido, *N*-(*m*-hexadecylphenyl)ureido, *N,N*-(2,5-di-*t*-pentylphenyl)-*N*'-ethylureido, and *t*-butylcarbonamido; sulfonamido, such as methylsulfonamido, benzenesulfonamido, *p*-tolylsulfonamido, *p*-dodecylbenzenesulfonamido, *N*-methyltetradecylsulfonamido, *N,N*-dipropylsulfamoylamino, and hexadecylsulfonamido; sulfamoyl, such as *N*-methylsulfamoyl, *N*-ethylsulfamoyl, *N,N*-dipropylsulfamoyl, *N*-hexadecylsulfamoyl, *N,N*-dimethylsulfamoyl, *N*-[3-(dodecyloxy)propyl]sulfamoyl, *N*-[4-(2,4-di-*t*-pentylphenoxy)butyl]sulfamoyl, *N*-methyl-*N*-tetradecylsulfamoyl, and *N*-dodecylsulfamoyl; carbamoyl, such as *N*-methylcarbamoyl, *N,N*-dibutylcarbamoyl, *N*-octadecylcarbamoyl, *N*-[4-(2,4-di-*t*-pentylphenoxy)butyl]carbamoyl, *N*-methyl-*N*-tetradecylcarbamoyl, and *N,N*-

dioctylcarbamoyl; acyl, such as acetyl, (2,4-di-*t*-amylphenoxy)acetyl, phenoxycarbonyl, *p*-dodecyloxyphenoxycarbonyl methoxycarbonyl, butoxycarbonyl, tetradecyloxy carbonyl, ethoxycarbonyl, benzyloxycarbonyl, 3-pentadecyloxy carbonyl, and dodecyloxy carbonyl; sulfonyl, such as

5 methoxysulfonyl, octyloxysulfonyl, tetradecyloxysulfonyl, 2-ethylhexyloxysulfonyl, phenoxysulfonyl, 2,4-di-*t*-pentylphenoxysulfonyl, methylsulfonyl, octylsulfonyl, 2-ethylhexylsulfonyl, dodecylsulfonyl, hexadecylsulfonyl, phenylsulfonyl, 4-nonylphenylsulfonyl, and *p*-tolylsulfonyl; sulfonyloxy, such as dodecylsulfonyloxy, and hexadecylsulfonyloxy; sulfinyl,

10 such as methylsulfinyl, octylsulfinyl, 2-ethylhexylsulfinyl, dodecylsulfinyl, hexadecylsulfinyl, phenylsulfinyl, 4-nonylphenylsulfinyl, and *p*-tolylsulfinyl; thio, such as ethylthio, octylthio, benzylthio, tetradecylthio, 2-(2,4-di-*t*-pentylphenoxy)ethylthio, phenylthio, 2-butoxy-5-*t*-octylphenylthio, and *p*-tolylthio; acyloxy, such as acetyloxy, benzoyloxy, octadecanoyloxy, *p*-

15 dodecylamidobenzoyloxy, *N*-phenylcarbamoyloxy, *N*-ethylcarbamoyloxy, and cyclohexylcarbonyloxy; amine, such as phenylanilino, 2-chloroanilino, diethylamine, dodecylamine; imino, such as 1 (*N*-phenylimido)ethyl, *N*-succinimido or 3-benzylhydantoinyl; phosphate, such as dimethylphosphate and ethylbutylphosphate; phosphite, such as diethyl and dihexylphosphite; a

20 heterocyclic group, a heterocyclic oxy group or a heterocyclic thio group, each of which may be substituted and which contain a 3 to 7 membered heterocyclic ring composed of carbon atoms and at least one hetero atom selected from the group consisting of oxygen, nitrogen, sulfur, phosphorous, or boron. such as 2-furyl, 2-thienyl, 2-benzimidazolyloxy or 2-benzothiazolyl; quaternary ammonium, such as

25 triethylammonium; quaternary phosphonium, such as triphenylphosphonium; and silyloxy, such as trimethylsilyloxy.

If desired, the substituents may themselves be further substituted one or more times with the described substituent groups. The particular substituents used may be selected by those skilled in the art to attain the desired desirable properties

30 for a specific application and can include, for example, electron-withdrawing groups, electron-donating groups, and steric groups. When a molecule may have two or more substituents, the substituents may be joined together to form a ring

such as a fused ring unless otherwise provided. Generally, the above groups and substituents thereof may include those having up to 48 carbon atoms, typically 1 to 36 carbon atoms and usually less than 24 carbon atoms, but greater numbers are possible depending on the particular substituents selected.

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#### General device architecture

The present invention can be employed in most OLED device configurations. These include very simple structures comprising a single anode and cathode to more complex devices, such as passive matrix displays comprised of orthogonal arrays of anodes and cathodes to form pixels, and active-matrix displays where each pixel is controlled independently, for example, with a thin film transistor (TFT).

There are numerous configurations of the organic layers wherein the present invention can be successfully practiced. Essential requirements are a cathode, an anode, an HTL and an LEL. A more typical structure is shown in Figure 1 and contains a substrate **101**, an anode **103**, an optional hole-injecting layer **105**, a hole-transporting layer **107**, a light-emitting layer **109**, an electron-transporting layer **111**, and a cathode **113**. These layers are described in detail below. Note that the substrate may alternatively be located adjacent to the cathode, or the substrate may actually constitute the anode or cathode. Also, the total combined thickness of the organic layers is preferably less than 500 nm.

#### Substrate

The substrate **101** can either be light transmissive or opaque, depending on the intended direction of light emission. The light transmissive property is desirable for viewing the EL emission through the substrate. Transparent glass or organic materials are commonly employed in such cases. For applications where the EL emission is viewed through the top electrode, the transmissive characteristic of the bottom support is immaterial, and therefore can be light transmissive, light absorbing or light reflective. Substrates for use in this case include, but are not limited to, glass, plastic, semiconductor materials,

ceramics, and circuit board materials. Of course it is necessary to provide in these device configurations a light-transparent top electrode.

#### Anode

5                   The conductive anode layer **103** is commonly formed over the substrate and, when EL emission is viewed through the anode, should be transparent or substantially transparent to the emission of interest. Common transparent anode materials used in this invention are indium-tin oxide (ITO) and tin oxide, but other metal oxides can work including, but not limited to,  
10 aluminum- or indium-doped zinc oxide (IZO), magnesium-indium oxide, and nickel-tungsten oxide. In addition to these oxides, metal nitrides, such as gallium nitride, and metal selenides, such as zinc selenide, and metal sulfides, such as zinc sulfide, can be used in layer **103**. For applications where EL emission is viewed through the top electrode, the transmissive characteristics of layer **103** are  
15 immaterial and any conductive material can be used, transparent, opaque or reflective. Example conductors for this application include, but are not limited to, gold, iridium, molybdenum, palladium, and platinum. Typical anode materials, transmissive or otherwise, have a work function of 4.1 eV or greater. Desired anode materials are commonly deposited by any suitable means such as  
20 evaporation, sputtering, chemical vapor deposition, or electrochemical means. Anodes can be patterned using well-known photolithographic processes.

#### Hole-Injecting Layer (HIL)

                  While not always necessary, it is often useful that a hole-injecting  
25 layer **105** be provided between anode **103** and hole-transporting layer **107**. The hole-injecting material can serve to improve the film formation property of subsequent organic layers and to facilitate injection of holes into the hole-transporting layer. Suitable materials for use in the hole-injecting layer include, but are not limited to, porphyrinic compounds such as those described in US  
30 4,720,432, and plasma-deposited fluorocarbon polymers such as those described in US 6,208,075. Alternative hole-injecting materials reportedly useful in organic EL devices are described in EP 0 891 121 A1 and EP 1 029 909 A1.

Hole-Transporting Layer (HTL)

The hole-transporting layer 107 of the organic EL device contains at least one hole-transporting compound such as an aromatic tertiary amine, where

5 the latter is understood to be a compound containing at least one trivalent nitrogen atom that is bonded only to carbon atoms, at least one of which is a member of an aromatic ring. In one form the aromatic tertiary amine can be an arylamine, such as a monoarylamine, diarylamine, triarylamine, or a polymeric arylamine group.

Exemplary monomeric triarylaminines are illustrated by Klupfel et al. US

10 3,180,730. Other suitable triarylaminines substituted with one or more vinyl radicals and/or comprising at least one active hydrogen containing group are disclosed by Brantley et al US 3,567,450 and US 3,658,520.

A more preferred class of aromatic tertiary amines are those which include at least two aromatic tertiary amine moieties as described in US 4,720,432

15 and US 5,061,569. Such compounds include those represented by structural formula (A).

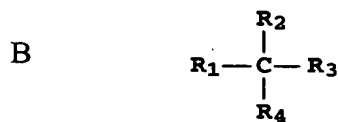


wherein Q<sub>1</sub> and Q<sub>2</sub> are independently selected aromatic tertiary amine moieties and G is a linking group such as an arylene, cycloalkylene, or alkylene group of a

20 carbon to carbon bond. In one embodiment, at least one of Q<sub>1</sub> or Q<sub>2</sub> contains a polycyclic fused ring group, e.g., a naphthalene. When G is an aryl group, it is conveniently a phenylene, biphenylene, or naphthalene group.

A useful class of triarylamine groups satisfying structural formula (A) and containing two triarylamine groups is represented by structural formula

25 (B):





where

R<sub>1</sub> and R<sub>2</sub> each independently represents a hydrogen atom, an aryl group, or an alkyl group or R<sub>1</sub> and R<sub>2</sub> together represent the atoms completing a cycloalkyl group; and

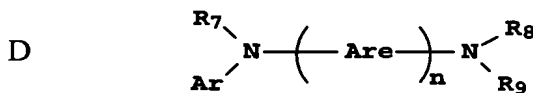
- 5            R<sub>3</sub> and R<sub>4</sub> each independently represents an aryl group, which is in turn substituted with a diaryl substituted amino group, as indicated by structural formula (C):



- 10        wherein R<sub>5</sub> and R<sub>6</sub> are independently selected aryl groups. In one embodiment, at least one of R<sub>5</sub> or R<sub>6</sub> contains a polycyclic fused ring group, e.g., a naphthalene.

Another class of aromatic tertiary amine groups is the tetraaryldiamines. Desirable tetraaryldiamines groups include two diarylamino groups, such as indicated by formula (C), and linked through an arylene group.

- 15        Useful tetraaryldiamines include those represented by formula (D).



wherein

each Are is an independently selected arylene group, such as a phenylene or anthracene group,

- 20            n is an integer of from 1 to 4, and

Ar, R<sub>7</sub>, R<sub>8</sub>, and R<sub>9</sub> are independently selected aryl groups.

In a typical embodiment, at least one of Ar, R<sub>7</sub>, R<sub>8</sub>, and R<sub>9</sub> is a polycyclic fused ring group, e.g., a naphthalene

- 25            The various alkyl, alkylene, aryl, and arylene groups of the foregoing structural formulae (A), (B), (C), (D), can each in turn be substituted. Typical substituents include alkyl groups, alkoxy groups, aryl groups, aryloxy groups, and halogen such as fluoride, chloride, and bromide. The various alkyl

and alkylene groups typically contain from about 1 to 6 carbon atoms. The cycloalkyl moieties can contain from 3 to about 10 carbon atoms, but typically contain five, six, or seven ring carbon atoms--e.g., cyclopentyl, cyclohexyl, and cycloheptyl ring structures. The aryl and arylene groups are usually phenyl and phenylene moieties.

The hole-transporting layer can be formed of a single or a mixture of aromatic tertiary amine compounds. Specifically, one may employ a triarylamine, such as a triarylamine satisfying the formula (B), in combination with a tetraaryldiamine, such as indicated by formula (D). When a triarylamine is employed in combination with a tetraaryldiamine, the latter is positioned as a layer interposed between the triarylamine and the electron injecting and transporting layer. Illustrative of useful aromatic tertiary amines are the following:

1,1-Bis(4-di-*p*-tolylaminophenyl)cyclohexane  
 1,1-Bis(4-di-*p*-tolylaminophenyl)-4-phenylcyclohexane  
 4,4'-Bis(diphenylamino)quadriphenyl  
 Bis(4-dimethylamino-2-methylphenyl)-phenylmethane  
*N,N,N*-Tri(*p*-tolyl)amine  
 4-(di-*p*-tolylamino)-4'-[4(di-*p*-tolylamino)-styryl]stilbene  
*N,N,N',N'*-Tetra-*p*-tolyl-4,4'-diaminobiphenyl  
*N,N,N',N'*-Tetraphenyl-4,4'-diaminobiphenyl  
*N,N,N',N'*-tetra-1-naphthyl-4,4'-diaminobiphenyl  
*N,N,N',N'*-tetra-2-naphthyl-4,4'-diaminobiphenyl  
*N*-Phenylcarbazole  
 4,4'-Bis[*N*-(1-naphthyl)-*N*-phenylamino]biphenyl  
 4,4'-Bis[*N*-(1-naphthyl)-*N*-(2-naphthyl)amino]biphenyl  
 4,4"-Bis[*N*-(1-naphthyl)-*N*-phenylamino]*p*-terphenyl  
 4,4'-Bis[*N*-(2-naphthyl)-*N*-phenylamino]biphenyl  
 4,4'-Bis[*N*-(3-acenaphthenyl)-*N*-phenylamino]biphenyl  
 1,5-Bis[*N*-(1-naphthyl)-*N*-phenylamino]naphthalene  
 4,4'-Bis[*N*-(9-anthryl)-*N*-phenylamino]biphenyl  
 4,4"-Bis[*N*-(1-anthryl)-*N*-phenylamino]-*p*-terphenyl

4,4'-Bis[*N*-(2-phenanthryl)-*N*-phenylamino]biphenyl  
 4,4'-Bis[*N*-(8-fluoranthenyl)-*N*-phenylamino]biphenyl  
 4,4'-Bis[*N*-(2-pyrenyl)-*N*-phenylamino]biphenyl  
 4,4'-Bis[*N*-(2-naphthacetyl)-*N*-phenylamino]biphenyl  
 5 4,4'-Bis[*N*-(2-perylenyl)-*N*-phenylamino]biphenyl  
 4,4'-Bis[*N*-(1-coronenyl)-*N*-phenylamino]biphenyl  
 2,6-Bis(di-*p*-tolylamino)naphthalene  
 2,6-Bis[di-(1-naphthyl)amino]naphthalene  
 2,6-Bis[*N*-(1-naphthyl)-*N*-(2-naphthyl)amino]naphthalene  
 10 *N,N,N',N'*-Tetra(2-naphthyl)-4,4''-diamino-*p*-terphenyl  
 4,4'-Bis{*N*-phenyl-*N*-[4-(1-naphthyl)-phenyl]amino}biphenyl  
 4,4'-Bis[*N*-phenyl-*N*-(2-pyrenyl)amino]biphenyl  
 2,6-Bis[*N,N*-di(2-naphthyl)amine]fluorine  
 1,5-Bis[*N*-(1-naphthyl)-*N*-phenylamino]naphthalene  
 15

Another class of useful hole-transporting materials includes polycyclic aromatic compounds as described in EP 1 009 041. In addition, polymeric hole-transporting materials can be used such as poly(*N*-vinylcarbazole) (PVK), polythiophenes, polypyrrole, polyaniline, and copolymers such as  
 20 poly(3,4-ethylenedioxythiophene) / poly(4-styrenesulfonate) also called PEDOT/PSS.

#### Light-Emitting Layer (LEL)

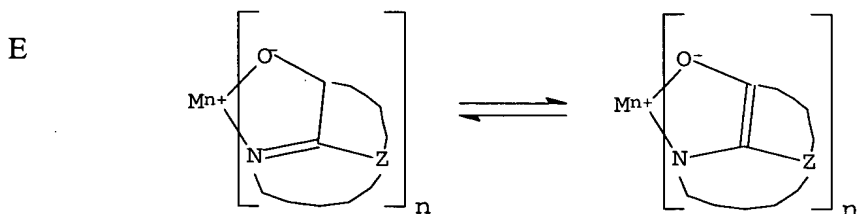
As more fully described in US 4,769,292 and 5,935,721, the light-emitting layer (LEL) 109 of the organic EL element comprises a luminescent or  
 25 fluorescent material where electroluminescence is produced as a result of electron-hole pair recombination in this region. The light-emitting layer can be comprised of a single material, but more commonly consists of a host material doped with a guest compound or compounds where light emission comes primarily from the  
 30 dopant and can be of any color. The host materials in the light-emitting layer can be an electron-transporting material, as defined below, a hole-transporting material, as defined above, or another material or combination of materials that

support hole-electron recombination. The dopant is usually chosen from highly fluorescent dyes, but phosphorescent compounds, e.g., transition metal complexes as described in WO 98/55561, WO 00/18851, WO 00/57676, and WO 00/70655 are also useful. Dopants are typically coated as 0.01 to 10 % by weight into the  
5 host material.

An important relationship for choosing a dye as a dopant is a comparison of the bandgap potential which is defined as the energy difference between the highest occupied molecular orbital and the lowest unoccupied molecular orbital of the molecule. For efficient energy transfer from the host to  
10 the dopant molecule, a necessary condition is that the band gap of the dopant is smaller than that of the host material.

Host and emitting molecules known to be of use include, but are not limited to, those disclosed in US 4,768,292, US 5,141,671, US 5,150,006, US 5,151,629, US 5,405,709, US 5,484,922, US 5,593,788, US 5,645,948, US  
15 5,683,823, US 5,755,999, US 5,928,802, US 5,935,720, US 5,935,721, and US 6,020,078.

Metal complexes of 8-hydroxyquinoline and similar derivatives (Formula E) constitute one class of useful host compounds capable of supporting electroluminescence, and are particularly suitable for light emission of  
20 wavelengths longer than 500 nm, e.g., green, yellow, orange, and red.



wherein

M represents a metal;

n is an integer of from 1 to 4; and

Z independently in each occurrence represents the atoms completing a  
25 nucleus having at least two fused aromatic rings.

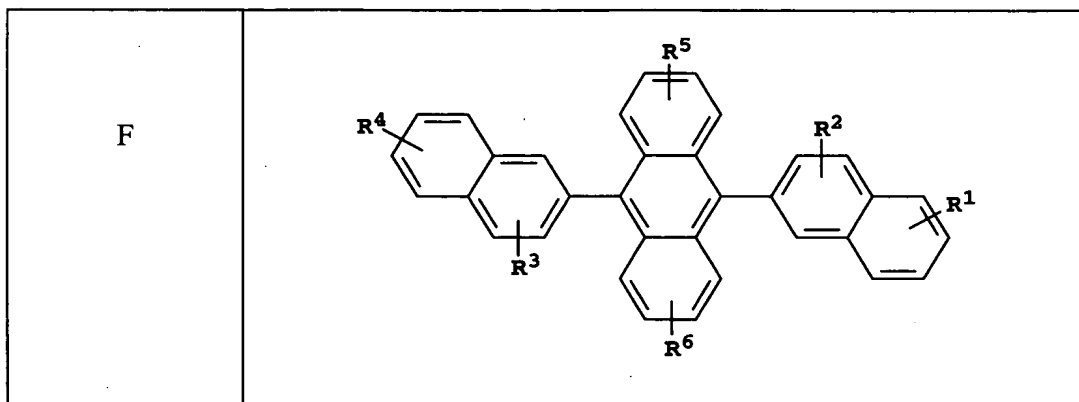
From the foregoing it is apparent that the metal can be monovalent, divalent, trivalent, or tetravalent metal. The metal can, for example, be an alkali metal, such as lithium, sodium, or potassium; an alkaline earth metal, such as magnesium or calcium; an earth metal, such aluminum or gallium, or a transition metal such as zinc or zirconium. Generally any monovalent, divalent, trivalent, or tetravalent metal known to be a useful chelating metal can be employed.

Z completes a heterocyclic nucleus containing at least two fused aromatic rings, at least one of which is an azole or azine ring. Additional rings, including both aliphatic and aromatic rings, can be fused with the two required rings, if required. To avoid adding molecular bulk without improving on function the number of ring atoms is usually maintained at 18 or less.

Illustrative of useful chelated oxinoid compounds are the following:

- CO-1: Aluminum trisoxine [alias, tris(8-quinolinolato)aluminum(III)]
- CO-2: Magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)]
- CO-3: Bis[benzo{f}-8-quinolinolato]zinc (II)
- CO-4: Bis(2-methyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(2-methyl-8-quinolinolato) aluminum(III)
- CO-5: Indium trisoxine [alias, tris(8-quinolinolato)indium]
- CO-6: Aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato)aluminum(III)]
- CO-7: Lithium oxine [alias, (8-quinolinolato)lithium(I)]
- CO-8: Gallium oxine [alias, tris(8-quinolinolato)gallium(III)]
- CO-9: Zirconium oxine [alias, tetra(8-quinolinolato)zirconium(IV)]
- CO-10: Bis(2-methyl-8-quinolinolato)-4-phenylphenolatoaluminum (III)

Derivatives of 9,10-di-(2-naphthyl)anthracene (Formula F) constitute one class of useful hosts capable of supporting electroluminescence, and are particularly suitable for light emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or red.



wherein:  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ , and  $R^6$  represent hydrogen or one or more substituents selected from the following groups:

Group 1: hydrogen, alkyl and alkoxy groups typically having from 1 to 24  
5 carbon atoms;

Group 2: a ring group, typically having from 6 to 20 carbon atoms;

Group 3: the atoms necessary to complete a carbocyclic fused ring group such as naphthyl, anthracenyl, pyrenyl, and perylenyl groups, typically having from 6 to 30 carbon atoms;

10 Group 4: the atoms necessary to complete a heterocyclic fused ring group such as furyl, thienyl, pyridyl, and quinoliny groups, typically having from 5 to 24 carbon atoms;

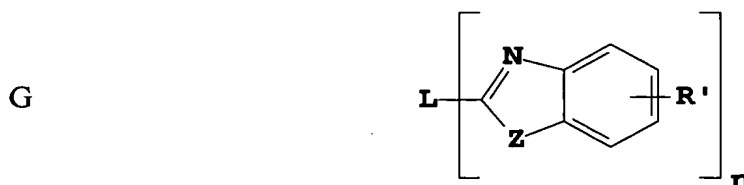
Group 5: an alkoxylamino, alkylamino, and arylamino group typically having from 1 to 24 carbon atoms; and

15 Group 6: fluorine, chlorine, bromine and cyano radicals.

Illustrative examples include 9,10-di-(2-naphthyl)anthracene and 2-*t*-butyl-9,10-di-(2-naphthyl)anthracene. Other anthracene derivatives can be useful as a host in the LEL, including derivatives of 9,10-bis[4-(2,2-  
20 diphenylethenyl)phenyl]anthracene, and phenylanthracene derivatives as described in EP 681,019.

Benzazole derivatives (Formula G) constitute another class of useful hosts capable of supporting electroluminescence, and are particularly

suitable for light emission of wavelengths longer than 400 nm, e.g., blue, green, yellow, orange or red.



where:

n is an integer of 3 to 8;

5 Z is -O, -NR or -S where R is H or a substituent; and

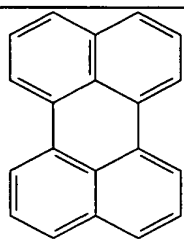
R' represents one or more optional substituents where R and each R' are H or alkyl groups such as propyl, t-butyl, and heptyl groups typically having from 1 to 24 carbon atoms; carbocyclic or heterocyclic ring groups such as phenyl and naphthyl, furyl, thienyl, pyridyl, and quinolinyl groups and atoms necessary to  
10 complete a fused aromatic ring group typically having from 5 to 20 carbon atoms; and halo such as chloro, and fluoro;

L is a linkage unit usually comprising an alkyl or aryl group which conjugately or unconjugately connects the multiple benzazoles together.

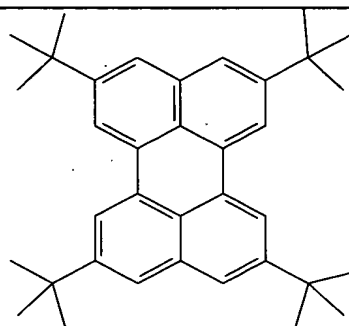
An example of a useful benzazole is 2, 2', 2''-(1,3,5-phenylene)tris[1-phenyl-1H-benzimidazole].  
15

Distyrylarylene derivatives as described in US 5,121,029 are also useful host materials in the LEL.

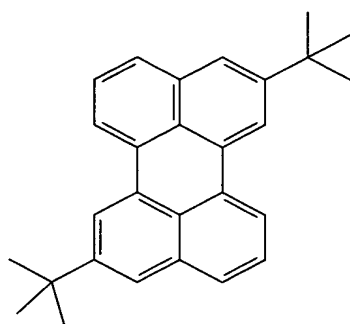
Desirable fluorescent dopants include groups derived from fused  
20 ring, heterocyclic and other compounds such as anthracene, tetracene, xanthene, perylene, rubrene, coumarin, rhodamine, quinacridone, dicyanomethylenepyran, thiopyran, polymethine, pyrilium thiapyrilium, and carbostyryl compounds. Illustrative examples of useful dopants include, but are not limited to, the following:



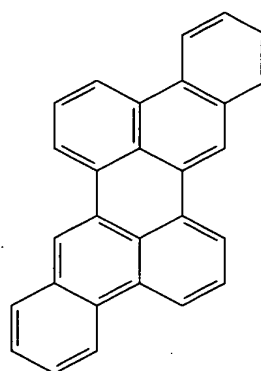
L1



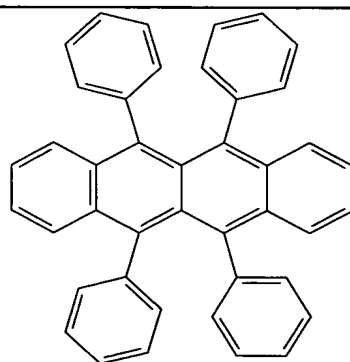
L2



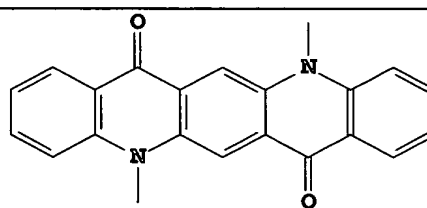
L3



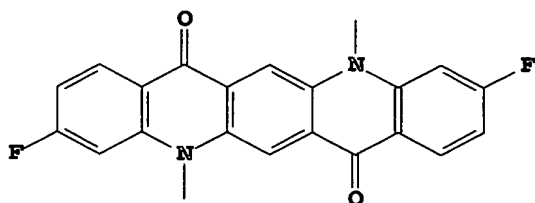
L4



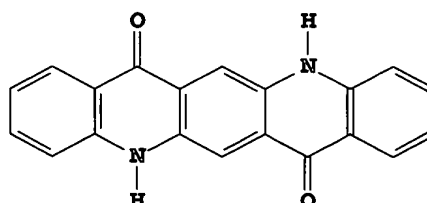
L5



L6



L7



L8

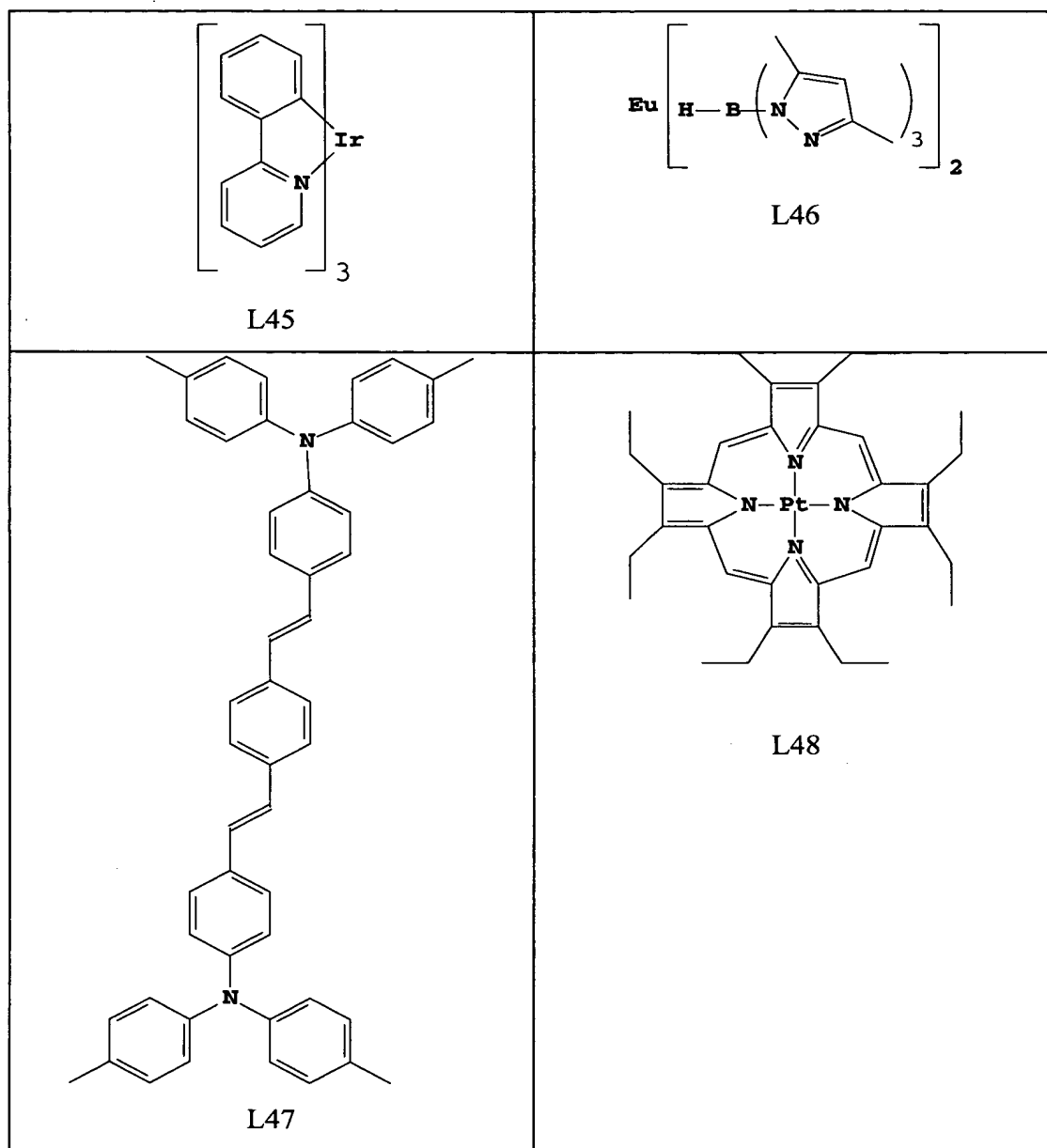


	X	R1	R2
L9	O	H	H
L10	O	H	Methyl
L11	O	Methyl	H
L12	O	Methyl	Methyl
L13	O	H	t-butyl
L14	O	t-butyl	H
L15	O	t-butyl	t-butyl
L16	S	H	H
L17	S	H	Methyl
L18	S	Methyl	H
L19	S	Methyl	Methyl
L20	S	H	t-butyl
L21	S	t-butyl	H
L22	S	t-butyl	t-butyl

	X	R1	R2
L23	O	H	H
L24	O	H	Methyl
L25	O	Methyl	H
L26	O	Methyl	Methyl
L27	O	H	t-butyl
L28	O	t-butyl	H
L29	O	t-butyl	t-butyl
L30	S	H	H
L31	S	H	Methyl
L32	S	Methyl	H
L33	S	Methyl	Methyl
L34	S	H	t-butyl
L35	S	t-butyl	H
L36	S	t-butyl	t-butyl

	R
L37	phenyl
L38	methyl
L39	t-butyl
L40	mesityl

	R
L41	phenyl
L42	methyl
L43	t-butyl
L44	mesityl



### Electron-Transporting Layer (ETL)

Preferred thin film-forming materials for use in forming the electron-transporting layer **111** of the organic EL devices of this invention are metal chelated oxinoid compounds, including chelates of oxine itself (also commonly referred to as 8-quinolinol or 8-hydroxyquinoline). Such compounds help to inject and transport electrons and exhibit both high levels of performance and are readily fabricated in the form of thin films. Exemplary of contemplated

oxinoid compounds are those satisfying structural formula (E), previously described.

Other electron-transporting materials include various butadiene derivatives as disclosed in US 4,356,429 and various heterocyclic optical brighteners as  
5 described in US 4,539,507. Benzazoles satisfying structural formula (G) are also useful electron transporting materials.

In some instances, layers **109** and **111** can optionally be collapsed into a single layer that serves the function of supporting both light emission and electron transportation.

10

### Cathode

When light emission is through the anode, the cathode layer **113** used in this invention can be comprised of nearly any conductive material. Desirable materials have good film-forming properties to ensure good contact  
15 with the underlying organic layer, promote electron injection at low voltage, and have good stability. Useful cathode materials often contain a low work function metal ( $< 4.0$  eV) or metal alloy. One preferred cathode material is comprised of a Mg:Ag alloy wherein the percentage of silver is in the range of 1 to 20 %, as described in US 4,885,221. Another suitable class of cathode materials includes  
20 bilayers comprised of a thin layer of a low work function metal or metal salt capped with a thicker layer of conductive metal. One such cathode is comprised of a thin layer of LiF followed by a thicker layer of Al as described in US 5,677,572. Other useful cathode materials include, but are not limited to, those disclosed in US 5,059,861, US 5,059,862, and US 6,140,763.

25 When light emission is viewed through the cathode, the cathode must be transparent or nearly transparent. For such applications, metals must be thin or one must use transparent conductive oxides, or a combination of these materials. Optically transparent cathodes have been described in more detail in US 5,776,623. Cathode materials can be deposited by evaporation, sputtering, or  
30 chemical vapor deposition. When needed, patterning can be achieved through many well known methods including, but not limited to, through-mask deposition,

integral shadow masking as described in US 5,276,380 and EP 0 732 868, laser ablation, and selective chemical vapor deposition.

#### Deposition of organic layers

5                   The organic materials mentioned above are suitably deposited through sublimation, but can be deposited from a solvent with an optional binder to improve film formation. If the material is a polymer, solvent deposition is usually preferred. The material to be deposited by sublimation can be vaporized from a sublimator "boat" often comprised of a tantalum material, e.g., as  
10 described in US 6,237,529, or can be first coated onto a donor sheet and then sublimed in closer proximity to the substrate. Layers with a mixture of materials can utilize separate sublimator boats or the materials can be pre-mixed and coated from a single boat or donor sheet. Patterned deposition can be achieved using shadow masks, integral shadow masks (US 5,294,870), spatially-defined thermal  
15 dye transfer from a donor sheet (US 5,851,709 and US 6,066,357) and inkjet method (US 6,066,357).

#### Encapsulation

                  Most OLED devices are sensitive to moisture and/or oxygen so  
20 they are commonly sealed in an inert atmosphere such as nitrogen or argon, along with a desiccant such as alumina, bauxite, calcium sulfate, clays, silica gel, zeolites, alkaline metal oxides, alkaline earth metal oxides, sulfates, or metal halides and perchlorates. Methods for encapsulation and desiccation include, but are not limited to, those described in US 6,226,890.

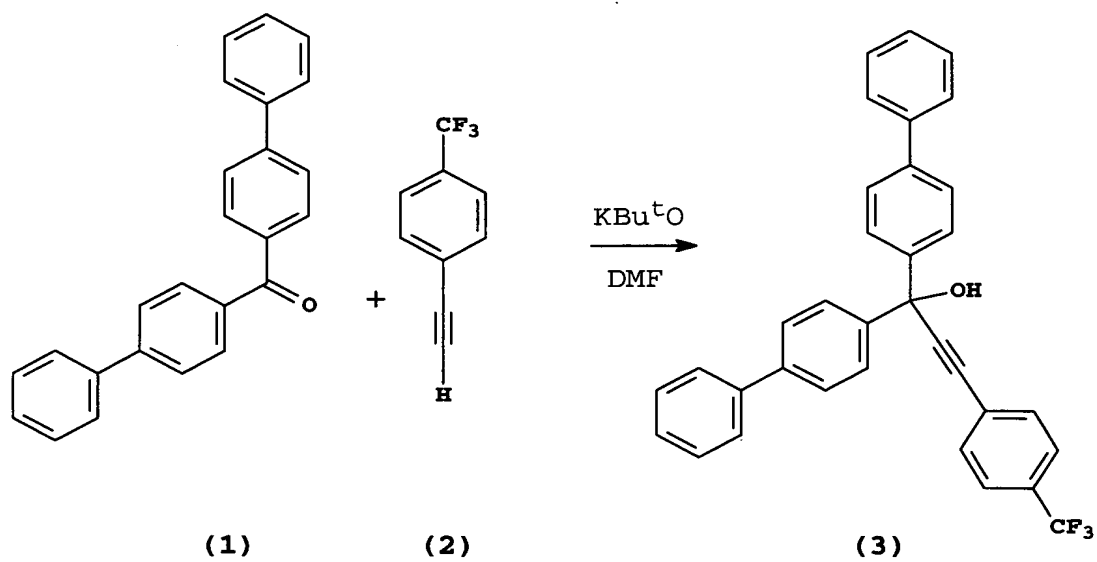
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                  The entire contents of the patents and other publications referred to in this specification are incorporated herein by reference.

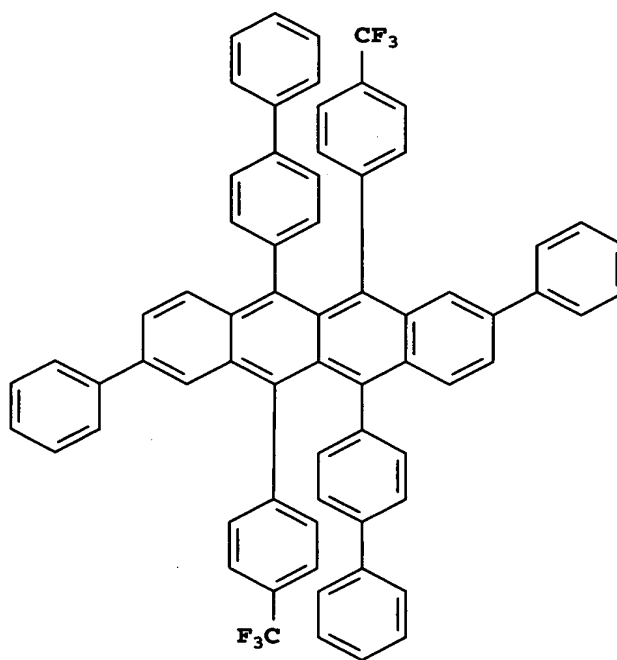
#### **EXAMPLES**

30                   The inventions and its advantages are further illustrated by the specific examples, which follow.

**Scheme 1**



1.  $\text{CH}_3\text{SO}_2\text{Cl}/\text{CH}_2\text{Cl}_2/\text{NEt}_3$
2. collidine/xylenes



**(Inv-2)**

**Example 1 - Synthesis (Scheme 1)**

Preparation of compound (3): Under a nitrogen atmosphere, acetylenic compound (2) (5.10g, 30mMole), was dissolved in dimethylformamide (DMF) (70mL) and the solution cool to 0 °C. Potassium t-butoxide (K<sup>t</sup>BuO) (4.04g, 36mMole), was added and the mixture stirred well for approximately 15 minutes. To this mixture was then added the benzophenone (1) (10g, 30mMole). Stirring was continued at 0 °C for approximately 30 minutes and then allowed to come to room temperature over a 1-hour period. At the end of this time the solution was cooled to 0 °C and the reaction treated with saturated sodium chloride (20mL). The mixture was then diluted with ethyl acetate, washed with 2N-HCl (x3), dried over MgSO<sub>4</sub>, filtered and concentrated under reduced pressure. The crude product was dissolved in 20% ethyl acetate in heptane and subjected to pressure chromatography over silica gel eluting with the same solvent mixture. The main material was collected.

Yield of compound (3), 10g.

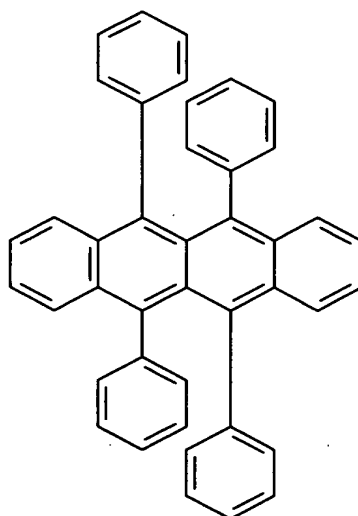
Preparation of Inventive Compound, **Inv-2**: Compound (3) (10g, 19.82mMole) was dissolved in methylene chloride (CH<sub>2</sub>Cl<sub>2</sub>) (70mL), and stirred at 0 °C under a nitrogen atmosphere. To this solution was added triethylamine (NEt<sub>3</sub>) (2.0g, 19.82mMole) and then treated drop by drop with methanesulfonyl chloride (CH<sub>3</sub>SO<sub>2</sub>Cl) (2.55g, 19.82mMole), keeping the temperature of the reaction in the range 0-5 °C. After the addition the solution was stirred at 0 °C for 30 minutes and then allowed to warm to room temperature over 1 hour. The reaction was then heated to reflux, distilling off the methylene chloride solvent and gradually replacing it with xylenes (a total of 70mL). When the internal temperature of the reaction reached 80 °C, collidine (2.40g, 19.82mMole), dissolved in xylenes (10mL) was added drop by drop over a 10-minute period. The temperature was then raised to 110 °C and held at this temperature for 4 hours. After this period the reaction was allowed to cool to approximately 80 °C and filtered. The filtrate was washed first with some xylenes and then methanol to give inventive compound **Inv-2** as a bright red solid. Yield 3.6g with a melting point of 360 °C. The

product may be further purified by sublimation (340 °C @ 200 millitorr) with a N<sub>2</sub> carrier gas.

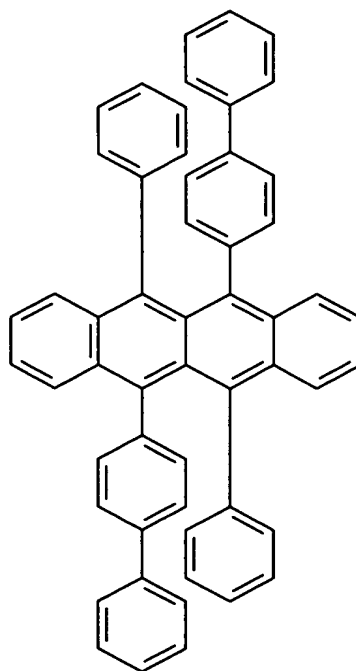
**Example 2 – Wavelength of maximum emission.**

- 5 The wavelengths of maximum emission, or  $\lambda_{\text{max}}$  of the compounds of the invention and comparative examples **Comp-1** through **Comp-3**, were obtained by dissolving the compounds in ethyl acetate and recording the emission spectra in a fluorimeter. The wavelengths of maximum emission are recorded in Table 1.
- 10 The comparative compounds used in the invention are as follows:

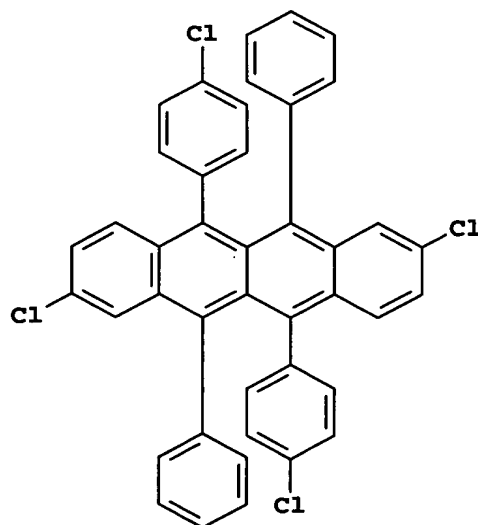
**Comp-1**



**Comp-2**



**Comp-3**



5

**Comp-1** is the parent rubrene. It is well known to those in the art and has no substituents on either of the end rings of the tetracene nucleus (2- and 8-positions), nor on the four phenyl rings located on the center rings of the tetracene. **Comp-2**  
 10 has phenyl substituents located on two of the four central phenyl rings of the



tetracene, diagonally opposite to each other, but falls outside the scope of the invention because it has no phenyl groups on the end rings of the tetracene nucleus, (2- and 8-positions). **Comp-3** was selected to show that not all substituents at the 2- and 8-positions are capable of shifting the emission  $\lambda_{\max}$  to longer wavelength.

**Table 1. Wavelength of Maximum Emission ( $\lambda_{\max}$ ).  
(Ethyl acetate Solution)**

Sample	Type	Compound	$\lambda_{\max}$ (nm)
1	Inventive	Inv-1	576
2	Inventive	Inv-2	576
3	Inventive	Inv-3	572
4	Inventive	Inv-4	576
5	Inventive	Inv-5	576
6	Inventive	Inv-9	580
7	Inventive	Inv-10	582
8	Inventive	Inv-14	576
9	Comparative	Comp-1	556
10	Comparative	Comp-2	560
11	Comparative	Comp-3	558

Table 1 shows that the comparison compounds have  $\lambda_{\max}$  values in the range 556-560nm in ethyl acetate solution, outside the range of the invention. Whereas, compounds of the invention show a desirable shift to longer wavelength and are in the range 572-582nm.

### **Example 3 – EL Device Fabrication – Inventive Example**

An EL device satisfying the requirements of the invention was constructed as Sample 12 in the following manner:

A glass substrate coated with an 85 nm layer of indium-tin oxide (ITO) as the anode was sequentially ultrasonicated in a commercial detergent, rinsed in deionized water, degreased in toluene vapor and exposed to oxygen plasma for about 1 min.

a) Over the ITO was deposited a 1 nm fluorocarbon (CF<sub>x</sub>) hole-injecting layer (HIL) by plasma-assisted deposition of CHF<sub>3</sub>.

b) A hole-transporting layer (HTL) of *N,N'*-di-1-naphthalenyl-*N,N'*-diphenyl-4, 4'-diaminobiphenyl (NPB) having a thickness of 150 nm was then  
5 evaporated from a tantalum boat.

c) A 37.5 nm light-emitting layer (LEL) of tris(8-quinolinolato)aluminum (III) (AlQ<sub>3</sub>) and **Inv-1** (1 and 2%-wt, see Tables 2 and 3) were then deposited onto the hole-transporting layer. These materials were also evaporated from tantalum boats.

10 d) A 37.5 nm electron-transporting layer (ETL) of tris(8-quinolinolato)aluminum (III) (AlQ<sub>3</sub>) was then deposited onto the light-emitting layer. This material was also evaporated from a tantalum boat.

e) On top of the AlQ<sub>3</sub> layer was deposited a 220 nm cathode formed of a 10:1 volume ratio of Mg and Ag.

15 The above sequence completed the deposition of the EL device. The device was then hermetically packaged in a dry glove box for protection against ambient environment.

Samples 13 through 16 were EL devices incorporating **Inv-2**, **Inv-3**, **Comp-2 and Comp-3** fabricated in an identical manner as the example  
20 incorporating **Inv-1**, at 1%-wt. Samples 17 through 22 were EL devices incorporating **Inv-1**, **Inv-2**, **Inv-3**, **Comp-1**, **Comp-2 and Comp-3** fabricated in an identical manner as the example incorporating **Inv-1** but at 2%-wt. The cells thus formed were tested for emission  $\lambda_{\text{max}}$  and efficiency (in the form of luminance yield), and the results are listed in Tables 2 and 3.

25

**Table 2. Evaluation Results for EL devices.**

Sample	Type	Host	Dopant (1%)	Efficiency (cd/A) <sup>1</sup>	$\lambda_{\max}$ (nm)
12	Inventive	ALQ <sub>3</sub>	Inv-1	5.28	572
13	Inventive	"	Inv-2	7.78	580
14	Inventive	"	Inv-3	7.62	576
15	Comparative	"	Comp-2	6.10	564
16	Comparative	"	Comp-3	6.40	560

<sup>1</sup> Luminance yields reported at 20 mA/cm<sup>2</sup>.

**Table 3. Evaluation Results for EL devices.**

Sample	Type	Host	Dopant (2%)	Efficiency (cd/A) <sup>1</sup>	$\lambda_{\max}$ (nm)
17	Inventive	ALQ <sub>3</sub>	Inv-1	4.97	576
18	Inventive	"	Inv-2	4.82	588
19	Inventive	"	Inv-3	6.06	580
20	Comparative	"	Comp-1	5.94	568
21	Comparative	"	Comp-2	6.5	564
22	Comparative	"	Comp-3	6.26	564

<sup>1</sup> Luminance yields reported at 20 mA/cm<sup>2</sup>.

5

As can be seen from Table 2, all tested EL devices incorporating the dopants of the invention at 1%-wt of the host, demonstrated high luminance yields. These doped EL devices exhibit orange-red electroluminescence with  $\lambda_{\max}$  ranging from 572-580nm. In contrast, the EL devices incorporating the comparative dopants exhibited electroluminescence with  $\lambda_{\max}$  ranging from 560-564nm. Table 3 shows all tested EL devices incorporating the dopants of the invention at 2%-wt of the host. At this level dopants of the invention also show good luminance yields and the  $\lambda_{\max}$  of the electroluminescence is in the range 576-588nm. In contrast, the EL devices incorporating the comparative dopants at 2%-wt exhibited electroluminescence with  $\lambda_{\max}$  only in the range of 564-568nm. The dopants of the invention are superior to the comparative dopants because they emit light shifted to longer wavelength.

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**PARTS LIST**

- 101 Substrate
- 103 Anode
- 105 Hole-Injecting layer (HIL)
- 107 Hole-Transporting layer (HTL)
- 109 Light-Emitting layer (LEL)
- 111 Electron-Transporting layer (ETL)
- 113 Cathode